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Soil Fertility Management of Sustainable Agriculture in Chinese Taipei

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Abstract

Of the major fertility management practices for wet rice, N fertilization is the most important. Since the type of cultivar and the climate have a profound effect on crop productivity, recommendations of N rates for rice are based primarily on the variety, the region and the cropping season. Recommendations of P and K rates are based primarily on results of soil testing for available P and K in the soil. There has, however, been a significant decline in rice response to these nutrients, compared with the response observed in the past, and in consequence there has been an accumulation of available P in the soil. More research should be done on whether further applications at such high rates are really needed. It is much stressed to develop the "on-site" and quick soil diagnosis to regulate and recommend rational fertilization in vegetable fields. Particularly in intensive cropped vegetable production for envionmental conservation. Leaf diagnosis and soil testing present as a guide for economic fertilization of orchards. Thus, The extension work of nutrient diagnosis in fertilizer recommendation service by leaf analysis and soil test should be strengthened and made really available to farmers.

Introduction

Soil fertility is the ability of a soil to deliver to roots the nutrients needed for the optimum growth of a specified crop. This ability is strongly influenced by the inherent soil characters, the interaction of these characters with the environment, and the management practices to which the soil is subjected. Thus, the soil fertility factors affecting crop production are quite complex and the fertility management even more complicated, because of the diversity of soils. Soil pH, organic matter content and the nutrient content of the soil are important parameters related to soil fertility (Lian 1989) . Leaf diagnosis and soil testing are valuable methods of determining the nutrient status of a crop and the soil in which it is growing, as a guide to what fertilizer is required.

As in all tropical and subtropical countries with year-round warm temperatures and high annual rainfall, the soils of Taiwan are constantly subject to rapid chemical decomposition and leaching. The depletion of soil fertility on most Taiwan's cultivated land is aggravated by highly intensive land use, whereby two to three or more crops are grown and harvested within each year. Therefore, the use of fertilizer to supplement soil nutrients plays an important role in crop production.

In Taiwan, the area planted each year in rice, fruit crops and vegetables are 339, 900 ha, 224,400 ha and 203,900 ha, respectively, corresponds to 32.3%, 21.3 % and 19.4% of total cropland. (Taiwan Agriculture Yearbook 2000) (Table 1). The application of chemical fertilizers and organic manures together with cultural practices are the major fertility management practices conducted in these cultivated soils of Taiwan. In this paper, fertility management of rice, vegetables and orchards cropland soils in Taiwan was discussed.

Fertility Management of Rice Soils

Rice yields depend primarily on the nitrogen fertility of the soil. Since nitrogen is the element most deficient in soil, the management of nitrogen fertility of soil is of major importance. The response in terms of rice yield to N, P, K over time is shown in Table 2. Of all the nutrient elements added, the yield response to nitrogen is the highest, It is also interesting to note that this response has maintained up to the present, in spite of the repeated applications of fertilizer over many years, This is because losses of N from both soil-N and added-N are fairly large when fertilizer N is added to the soil, so that the net increase of N in the soil is small.

The decomposition and transformation of soil organic nitrogen into nitrogen available to plants is a biological process which is affected by weather, soil texture, the presence of clay minerals, soil management, the nature of the previous crop and other variables. The evaluation of available N in the soil is thus more difficult than that of available P and K.

Rice productivity differs greatly in different area of Taiwan, depending on cultivars, climatic conditions, cultural techniques and soils. Of these four factors, cultivar and climatic conditions are considered to be most influential on crop productivity. Thus, the recommendation of N rates for rice on various soils primarily base on the variety, the area and the cropping season. The general pattern of recommendations, shown in Table 3, is based on the results of many field experiments.

The response of rice to phosphate and potash is generally lower than the response to nitrogen. Average consumption of P_2O_5 and K_2O per crop has increased to 34.3 and 46.3 kg/ha, respectively (average per crop during 1966-1986, despite the falling response) . As shown in Table 2, the average yield response of rice soils

in Taiwan to P and K fertilizers in years is only 0.6-0.8 and 0.7-1.5%, respectively, compared to that in past years (1929-1942 and 1953-1955), which reached as high as 5.4-6.7 for P and 2.4-5.1% for K.

Tables 4 and 5 show recommended rates of P_2O_5 and K_2O for rice soils according to soil test value of available P and K. These recommendations are based on the field calibrations of soil test carried out by various organizations from 1962 to 1968, revised and summarized by Su (1975). Special attention is given to increasing the level of potash applications in areas where drainage is poor. These criteria for P and K recommendations need to be revised, in view of the fall in the response of rice to these fertilizers A revision has been made which gives lower levels of available P to define the various classes, as shown by the values in parentheses given in Table 4. Table 6 shows that after continuously applied P fertilizers, soil available P in soil is increased (1978-1981), compare to that in past years (1959-1967).

In practice, rice in Taiwan today rarely receives applications of organic manure or green manure, except sometimes if upland crops are grown in rice fields as part of a crop rotation sequence. Organic matter content does not decrease, and may even increase, if chemical fertilizers alone are applied to rice fields. This is clearly shown in Table 7, compared to soils with a high or low organic matter content in past years in Taiwan.

Rice yield has increased very much, as indicated in Fig 1 which shows the yields in different years during 1937-1965, 1966-1986 and 1986-2000. This increase has generally been attributed to improvements both in rice varieties, which is with a higher response to N applications, and in cultivation techniques, including more efficient use of fertilizer and better control of insect pests and diseases.

Soils are acid either because their parent materials were acid and low in basic cations or because these elements have been removed from the profile by leaching or by the repeated harvesting of crops. Soil acidification is intensified by the use of nitrogenous fertilizers and by acid deposition from polluted air (Huang 1994).

Table 8 show the distribution of soils pH in Taiwan (1978-1981), which are lower compared to past years (1959-1967). Recent survey data also revealed that, in some area, soil pH decline continuously, and organic matter content are higher than that of past years(1978-1981) (Table 9)(Gao *et al*. 2001). Liming to correct soil acidity is also very important. A reclamation program for acidic soils has been established to encourage farmers to apply liming materials to strongly acidic farmland. So far, the program covers 5,000 ha of acidic arable land which is now under of reclamation (cropland soil fertility improvement project 2003).

Fertility Management of Vegetable Fields Soil

The negative aspects of the overuse of fertilizers have long been a concern in many parts of Taiwan. The environmental risk of using too much fertilizer is probably highest in intensively cropped vegetable fields where multiple crops are grown each year. In Taiwan, the year-round warm temperatures make it possible to grow 6 – 10 crops of vegetables each year. Very large amounts of both organic and chemical fertilizer are usually applied in vegetable production. The accumulation of salts and the risk of groundwater pollution by nitrates resulting from this intensive production may be the highest among all cropping systems. Table 10 and Table 11 show that there are significantly higher soil pH, organic matter content and EC (electric conductivity ds/m) in vegetable fields compared to the nearby paddy fields, and large amount of soluble salts accumulated (available P, exchangeable K, Ca, Mg) are visible in vegetable field (the total number of samples measured was 147 within Tao- Yuan area 1999) (Wang *et al.*2000b) .

Soil salinization of vegetable fields cultivated in facilities present another problem caused by overuse of fertilizers. With limited leaching, excessive salts largely move upward along with the evaporation of water and accumulated in the surface soil, which then hindered the seed germination and crop growth (Table 10) (Wang *et al.* 2000b) .

Table 12 and Fig 2 demonstrated that there was a significant leaching of NO_3^- down into the 150 cm depth soil and the amount of NO_3^--N already exceeded the 10 ppm limit set for drinking water (Wang 1994 , Wang *et al.* 2001b).

Recently, the development of soil test and improvement for determing the residual nitrogen in vegetable fields was undertaking, a new and simple technique of "on site" diagnosis of N fertility and its rapid recommendations of N fertilizer on leafy vegetable fields has established ; To reduce the nitrate or nitrite risks on environment the quick test methods of soil available N are assessed for on-site diagnosis and rapid fertilizer recommendation are now available in leafy vegetable fields. In laboratory, the results of incubation leaching and chemical extraction methods indicate available N contents detected by chemical extraction of 10% KCl, hot KCl and hot water are all positively and significantly correlated with those by incubation leaching. Relative yield of non nitrogen treatment reached 100%, when N content detected by chemical extraction fell in the 100ppm, 150ppm and 20ppm(Wang *et al.* 2000a, 2001b). Moreover, In field and pot experiment, there is extremely significant and linear relationships between available N contents and electric conductivity (EC,1 : 5) , and can be discribed by the equations : $Y=252.08X+2.0063$ ($n=23$, $R^2=0.7643^{**}$, from pot experiments) , and $Y=250.39X+0.2584$ ($n=22$, $R^2=0.6363^{**}$, from field experiments) . Here, Y is EC value ; X is NO^-_3-N extracted by 10% KCl(Fig. 3 and Fig. 4). Based on the results

above, the on-site N diagnosis could well be implemented in leafy vegetable fields with facilities. It would be recommended to withhold N fertilizer when determined EC larger than 0.4 mS/cm (suggesting soil NO^-_3-N over 100 $mgkg^{-1}$), either in fields equipped with plastic house susceptible to salt affected problem due to high evaporation and without rainfall leaching, or poorly drained fields with salts accumulated. When EC values fall in the ranges of 0.4-0.3,0.3-0.2 and 0.2-0.1 mS/cm, the N fertilizer rate should reduce to 1/4,1/2 and 3/4 of conventional rate cited in "Crop Fertilization Handbook", respectively. As of EC less than 0.1 mS/cm, the N rate would be recommended as referred to Crop Fertilization Handbook. Suggested N rate by rapid diagnosis, however, should be adjusted and increased in fields of well drainage (N loss prone to infiltration) or low soil organic matter level (below 3.0%) (Table 13), as soil N dynamics profoundly influenced by soil moisture and soil organic matter level. Consequently, development of soil quick test can promoted not only rational use of fertilizer to reduce production cost but also contributed to environment conservation (Wang *et al.* 2002a, 2002b).

Fertility Management of Orchards Soil

Leaf analysis and soil test are presently considered best tools for the diagnosis of fruit crops nutrition and orchard soil fertility. Leaf analysis and soil tests could present a good guide for proper fertilizer rate and soil management to farmers. A center for soil test and plant analysis has been organized in the Agricultural Research Institute. Well-equipped with automatic analysis instruments, and a computerized information system, the center provides accurate interpretation of leaf analysis and soil tests, as well as fertilization recommendations to farmers. In addition, an integrated orchard database has been established to integrate the results of accumulated long-term field surveys and trials. Thus, valuable information concerning diagnosis of nutrient status and fertilizer recommendation in orchards, long-term transition of soil fertility, together with regional statistics for leaf nutrient content, soil fertility, and fertilizer rates is all available to researchers and farmers.

Soil properties related to fertility level, such as pH, organic matter content, and soil texture as well as conventional fertilizer rates were also taken into account in the diagnosis and recommendation process. The nutrient elements diagnosed are nitrogen, phosphorus, potassium, calcium, magnesium, boron, copper, iron, manganese, and zinc. Criteria for eight kinds of orchards, i.e. citrus, grape, pear, loquat, carambola, mango, wax apple, and custard apple were collected in the diagnosis program. Even for the same kind fruit tree, different criteria are applied for different varieties and different crops growing in different seasons.

The diagnosis criteria are mostly derived from long term field survey and trials conducted in Taiwan. Because of limited information about some fruit trees, their criteria are adopted from foreign references and calibrated by further survey

and experiments conducted in Taiwan. Table 14 and Table 15 lists the optimum nutrient status and sampling methods for nutrient diagnosis of various fruit trees in Taiwan (Wang *et al.* 2000b, Chen *et al.*2001).

Leaf analysis is considered a handy tool for nutritional diagnosis and fertilization recommendations for orchards. The nutrient concentrations in a representative leaf sample can reflect the nutritional status of an orchard. Soil test, on the other hand, is not as useful for this purpose. This is because fertilizers are usually unevenly applied in orchards. Furthermore, the root systems of fruit trees can be very deep, so it is not easy to sample the soil representatively for diagnosistic purposes. A further point is that the nutritional status of a tree is the overall performance of the management history of the orchard in which it is growing, so the relationship between the N, P and K status of the soil and the condition of the tree may have little significance (Chang *et al.* 1992).Therefore, nutritional diagnosis and fertilization recommendations for orchards are mainly based on leaf diagnosis. Around 30,307 soil and 18,876 plant samples were taken and analyzed by the Agricultural Research Institute during 1989 to 2002 (Fig. 5). Reports of the analysis and fertilization recommendations were sent directly to the grower.

Conclusion

1. Of the major fertility management practices for wet rice, N fertilization is the most important. Since the type of cultivar and the climate have a profound effect on crop productivity, recommendations of N rates for rice are based primarily on the variety, the region and the cropping season. Recommendations of P and K rates are based primarily on results of soil testing for available P and K in the soil. There has, however, been a significant decline in rice response to these nutrients, compared with the response observed in the past, and in consequence there has been an accumulation of available P in the soil. More research should be done on whether further applications at such high rates are really needed.
2. It is much stressed to develop the "on-site" and quick soil diagnosis to regulate and recommend rational fertilization in vegetable fields. Particularly in intensive cropped vegetable production for envionmental conservation.
3. Leaf diagnosis and soil testing present as a guide for economic fertilization of orchards. Thus, The extension work of nutrient diagnosis in fertilizer recommendation service by leaf analysis and soil test should be strengthened and made really available to farmers.

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Table 1. Distribution of planting area of various crops in Taiwan

Year	1945		1970		1990		2000	
Crops	1,000ha	% of total	1,000ha	% of total	1,000ha	% of total	1,000ha	% of total
Rice	502.0	55.6	776.1	46.9	454.3	41.8	339.9	32.3
Grain crops	11.3	1.3	30.2	1.8	81.8	7.5	72.1	6.9
Legumes	39.9	4.4	153.4	9.3	7.7	0.7	117.9	11.2
Root crops	137.4	15.2	253.5	15.3	13.0	1.2	11.3	1.1
Tea	34.3	3.8	34.4	2.1	24.3	2.2	19.7	1.9
Tobacco	3.6	0.4	11.1	0.7	7.6	0.7	4.1	0.4
Sugarcane	107.7	11.9	87.5	5.3	69.1	6.4	38.9	3.7
Vegetables	35.3	3.9	141.5	8.5	188.2	17.3	203.9	19.4
Fruit crops	18.1	2.0	119.9	7.2	222.8	20.5	224.4	21.3
Flowers	0	0.0	0	0.0	6.2	0.6	11.0	1.0
Others	13.8	1.5	48.4	2.9	10.6	1.1	8.6	0.8
Total	903.5	100.0	1,656.0	100.0	1,085.6	100.0	1,051.8	100.0

Source: Taiwan Agriculture Year book.

Table 2. Response in terms of rice yield to nitrogen, phosphorus, potassium since 1929

Period in which experiments were conducted	Cropping season	No. locations	Experimental plots			
			-N	-P	-K	Complete[z]
1929-1942[y]	1st	117	72.6	94.0	97.6	100 (3,923)
1929-1942	2nd	117	76.4	93.3	94.9	100 (3,373)
1953-1955[x]	1st	82	66.8	94.6	97.8	100 (3,859)
1953-1955	2nd	91	75.0	94.5	95.6	100 (3,471)
1982-1983[w]	1st	80	75.2	99.4	99.3	100 (6,423)
1982-1983	2nd	80	81.2	99.2	98.5	100 (5,510)

[z] Expressed as yield index, 100 being the yield of the complete (NPK) plot. The numerical value (kg/ha) of the yield in the complete plot is shown in parenthesis.
[y] Source : Chu 1961.
[x] Source : Tseng 1961.
[w] Source : Lin 1984, Lin 1985.

Table 3. Recommended rates of N for wet rice production in Taiwan

Variety	Region[z]	N rate (kg/ha)[y]	
		1st crop	2nd crop
Japonica (medium height)	CSE	120-150	100-130
	N	110-130	100-120
japonica in excessively well-drained soil	CSE	180-210	170-200
	N	150	140
Indica (dwarf)	CSE	150-180	125-160

[z] C, S, E and N signify central, southern, eastern and northern Taiwan, respectively.
[y] The N rate should be raised by 10-20% if the direct-seeding system is used, and should be increased by 20-40 kg/ha in calcareous soils.
Source: Su 1975.

Table 4. Recommended rates of phosphate for wet rice production in Taiwan

Available P (Bray No. 1)			P_2O_5 rate (kg/ha)	
rating	mg/kg		1st crop	2nd crop
Very low	0-4	(0-1.6)[z]	70-80	50-60
Low	5-10	(1.7-5.0)	60-70	40-50
Medium	11-20	(5.1-12)	40-60	20-40
High	21-50	(12.1-30)	20-40	0-30
Very high	>50	(>30)	0-30	0-20

[z] Revised in 1987.
Source: Crop Fertilization Handbook 1983, Su 1975.

Table 5. Recommended rates of potash for wet rice production in Taiwan

Available K (Mehlich's)		K_2O rate (kg/ha)[z]	
rating	mg/kg	1st crop	2nd crop
Very low	0-15	60-70	80-90
Low	16-30	50-60	60-80
Medium	31-50[y]	30-50	40-60
High	>50[y]	0-30	0-40

[z] Plus 30 kg K_2O/ha in the case of poorly drained soils.
[y] For sandston ppm.
Source: Su 197e/shale alluvial soils and latosolic soils in northern Taiwan, M:31-70 ppm; H: >705.

Table 6. Comparison of the percentage distribution of soil available P level in past years

Available P in soil (Bray NO. 1)		1959-1967[z] (%)	1978-1981[y] (%)
rating	mg/kg		
Very low	0-4	7	5
Low	5-10	30	11
Medium	11-20	32	22
High	>20	31	62

[z] Soil fertility survey; the total number of samples measured was 78,600. Source:Lin *et al.* 1967.

[y] Soil fertility capability classification survey; the total number of samples measured was 5,730.

Source:Lin 1981.

Table 7. Comparison of the percentage distribution of surface soil organic matter content in past years

Organic matter content in soil		1959-1967[z] (%)	1978-1981[y] (%)
rating	g/kg		
Very low	<10	14.0	6.7
Low	10-20	50.6	38.1
Medium	20-30	26.9	33.1
High	30-40	8.3	16.0
Very high	>40	-	6.1

[z] Soil fertility survey; the total number of samples measured was 78,600. Source:Lin *et al.* 1967.

[y] Soil fertility capability classification survey; the total number of samples measured was 5,730.

Source:Lin 1981.

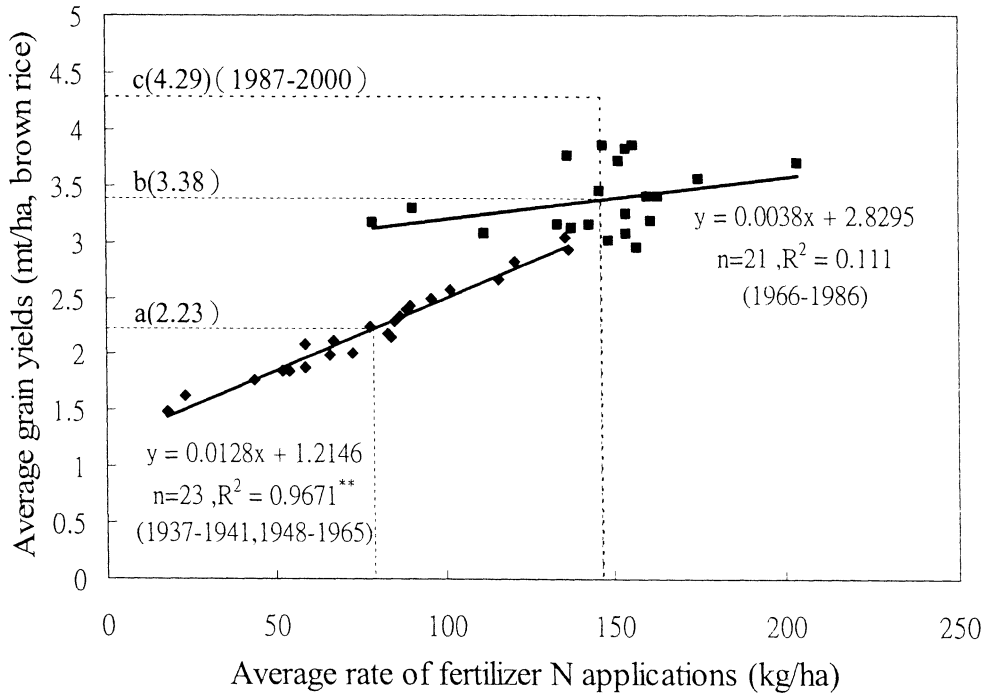

Fig.1. Relationship between average rice yields and rate of N applications over the period 1937-2000 in Taiwan.(Average of the 1st and 2nd crop, plotted from the statistical data of the Fertilizer Handbook 2003),(a,b,c: average rice yield of three stage respectively)

Table 8. Comparison of the percentage distribution of surface soil pH level in past years

Soil pH		1959-1967[z]	1978-1981[y]
rating	value	(%)	(%)
Strong acidic	<5.5	33.2	38.1
Acidic	5.5-6.5	25.2	23.9
Neutral	6.5-7.5	16.0	15.3
Alkali	7.5-8.5	22.3	22.0
Strong alkali	>8.5	3.4	0.7

[z] Soil fertility survey; the total number of samples measured was 78,600. Source: Lin *et al.* 1967.

[y] Soil fertility capability classification survey; the total number of samples measured was 5,730.

Source: Lin 1981.

Table 9. Comparison of surface soil pH and organic matter content of some villages in past and recent years

Location	pH		O.M.(g/kg)	
	1981	1994	1981	1994
Sin Chen	6.3±0.9[z)] (21)	6.4±1.0 (213)	25.2±9.3 (21)	26.0±11.7 (213)
Ji An	7.6±0.4 (21)	7.6±0.5 (494)	22.1±5.7 (21)	22.4±6.6 (494)
Chih Shang	6.5±0.6 (19)	5.7±1.0 (493)	28.9±6.3 (19)	33.9±10.4 (493)
Pei Na	6.5±0.9 (19)	5.3±1.1 (502)	28.9±8.2 (19)	26.4±8.8 (502)
Da Du	6.4±0.6 (8)	6.0±1.0 (220)	15.7±7.5 (8)	13.4±6.1 (220)
Yung Kang	5.3±0.6 (5)	6.5±1.1 (308)	11.0±4.2 (5)	16.1±5.6 (308)
Chang Hua	6.5±0.7 (20)	6.2±0.7 (469)	24.4±6.3 (20)	29.3±9.6 (469)
Ho Mei	6.5±0.6 (42)	5.9±0.8 (522)	20.6±5.4 (42)	26.6±14.0 (522)

[z] : means with standard deviation, the samples no. showed in parenthesis.
Source : Gao *et al.* 2001.

Table 10. Percentage distribution ratio of surface soil pH, organic matter content and EC in 147 vegetable fields (Tao Yuan,1999)

pH (1:1)		O.M.		EC (1:5)	
range	(%)	range g/kg	(%)	range dS/m	(%)
<5.0~4.5	10.9	<20	0	<0.5	33.3
<5.5~5.0	10.9	<30~20	15.7	<1~0.5	35.4
<6.0~5.5	15.7	<40~30	67.3	<1.5~1.0	13.6
<6.5~6.0	18.4	<50~40	13.6	<2.0~1.5	8.8
<7.0~6.5	12.3	<60~50	1.4	<2.5~2.0	5.4
≧7.0	29.3	≧60	2.0	≧2.5	3.4
Total	100		100		100

Source : Wang *et al.* 2000b.

Table 11. Percentage distribution of surface soil available P and exchangeable K, Ca and Mg content in 147 vegetable fields (Tao Yuan, 1999)

Bray NO.1 P		exch. K		exch. Ca		exch. Mg	
range mg/kg	(%)	range mg/kg	(%)	range cmol/kg	(%)	range cmol/kg	(%)
<100	2.0	<200	1.4	<10	21.1	<3.0	15.7
<200~100	8.2	<1000~200	53.1	<20~10	26.5	<6.0~3.0	34.0
<300~200	45.6	<1500~1000	27.2	<30~20	29.3	<9.0~6.0	36.7
<400~300	40.8	<2000~1500	11.6	<40~30	20.4	<12.0~9.0	12.9
≧400	3.4	≧2000	67	≧40	2.7	≧12.0	0.7
Total	100		100		100		100

Source : Wang *et al.* 2000b.

Table 12. Comparison of the NH_4^+-N and NO_3^--N concentrations in the water -saturated soil solution sampled at different soil depth either from a rice paddy or from a vegetable field (mg/kg)

Crops	Form of N		30 cm	50 cm	100 cm	150 cm
Rice	NH_4^+-N	Range	0.3-1.4	0.3-1.6	0.4-1.9	0.1-1.4
		Average	0.9 ± 0.5	0.7 ± 0.4	0.8 ± 0.4	0.6 ± 0.4
	NO_3^--N	Range	0.4-2.6	0.3-4.8	0.2-5.9	0.5-5.3
		Average	1.2 ± 0.8	2.1 ± 1.6	2.3 ± 1.1	1.7 ± 1.6
Vegetables	NH_4^+-N	Range	1.6-2.3	0.2-2.9	0.2-7.5	0.1-5.2
		Average	1.8 ± 0.3	1.5 ± 1.0	2.1 ± 1.8	1.9 ± 1.5
	NO_3^--N	Range	45-197	9-128	1.6-35	2.4-35
		Average	81 ± 65	39 ± 35	15 ± 13	14 ± 9

Source : Wang, Tan and Huang 1994.
Soil texture : Fine sandy loam.
Fertilization :
a)Rice paddy: chemical fertilizer N-P_2O_5-K_2O = 160-60-120 kg/ ha/crop ;
b)Vegetable field: chicken manure 1800kg/ha plus chemical fertilizer N-P_2O_5-K_2O = 750-350-540 kg/ ha/ 5 crop.

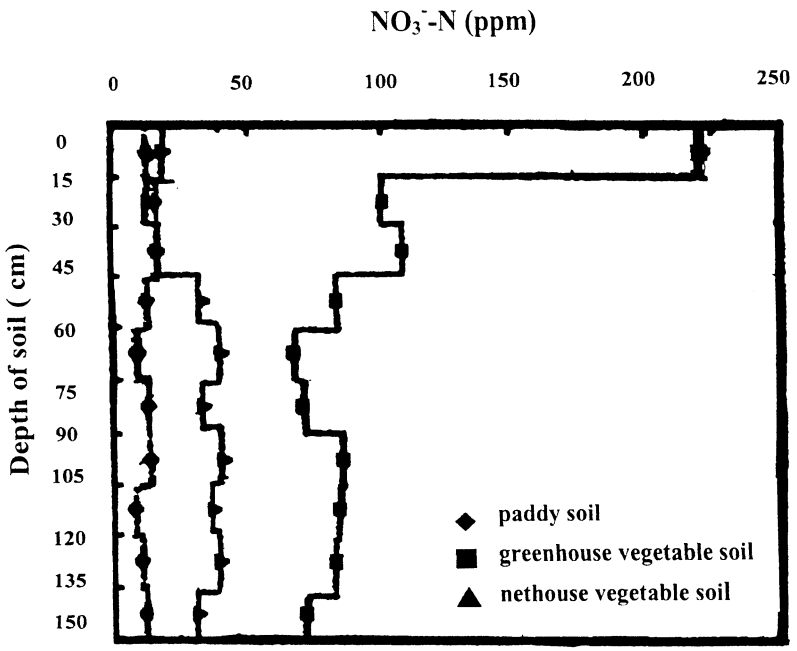

Fig.2. Level of nitrate-N in the profile of a vegetable soil compared with that in the nearby paddy soil , at the time of harvest (Hsilo 1995)
Source: Wang *et al.* 2001b.

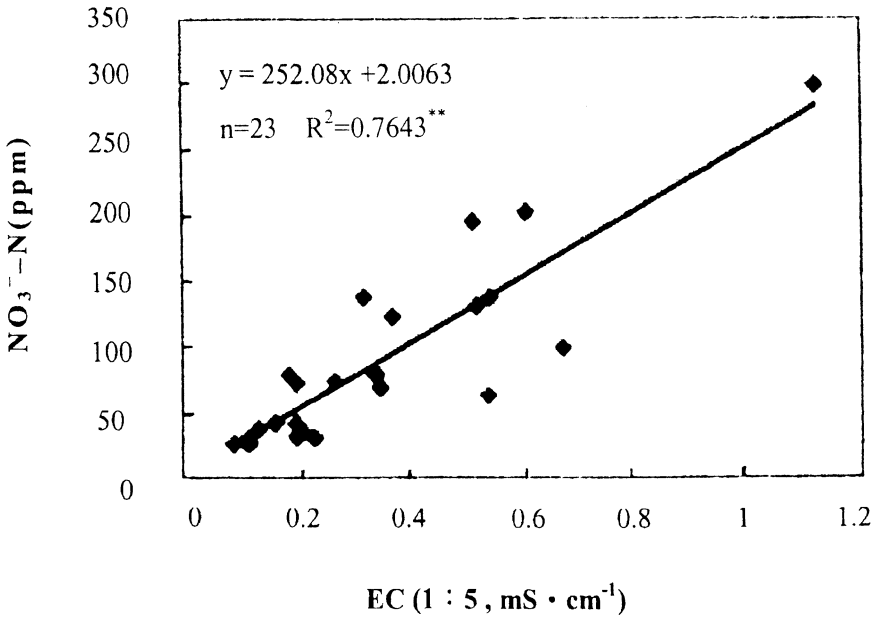

Fig.3. Relationship between EC value and NO_3^--N content in pot experiments
Source: Wang *et al.*2002a ,2002b.

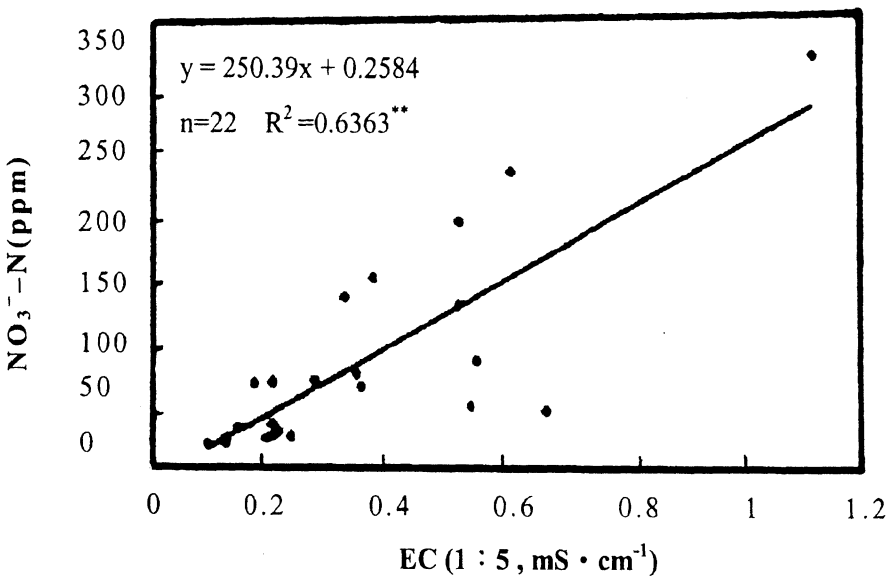

Fig.4. Relationship between EC value and NO_3^--N content in vegetable fields (Yungching 1998)
Source: Wang *et al.*2002a,2002b.

Table 13. Recommended rates of nitrogen in accordance with the EC value of leaf vegetable fields

EC (1:5)	NO_3^--N in surface soil		Recommended N. rates	
dS/m	mg/Kg	Kg/ha[y]	A[w]	B[x]
>0.4	>100[z]	>200	0/4 · R[v]	1/4 · R
0.4-0.3	100-75	200-150	1/4 · R	2/4 · R
0.3-0.2	75-50	150-100	2/4 · R	3/4 · R
0.2-0.1	50-25	100-50	3/4 · R	R
<0.1	<25	<50	R	R

[z] Derived from Fig.4.
[y] Calculated from NO_3^--N content multiple 2 million Kg surface soil per ha.
[w] In fields equiped with plastic house susceptible to salt affected problem, or poorly drained fields with salts accumulated.
[x] In fields with well drainage or lower organic matter content (below 3.0%) .
[v] R: Recommended N rate according to Crop Fertilization Handbook.
Source: Wang *et al.* 2002a , 2002b.

Table 14. Leaf diagnosis criteria for various fruit trees in Taiwan

Fruit tree	N	P	K	Ca	Mg	B	Ca	Fe	Mn	Zn
	----------%----------					----------ppm----------				
Citrus	3.0-3.2(Ponkan & Tunkan) 2.9-3.1(Liucheng & Other)	0.12-0.18	1.4-1.7	2.5-4.5	0.26-0.50	25-150	5-16	60-120	25-200	25-100
Grape	2.1-2.6(summer fruit) 2.4-2.8(winter fruit)	0.16-0.22	0.7-1.2 0.9-1.6	1.0-2.0 2.0-2.7	0.26-0.50	30-100	5-20	70-120	25-200	26-140
Pear	2.0-2.6	0.12-0.20	1.2-2.0	1.25-2.0	0.27-0.50	20-150	10-20	35-200	30-200	20-90
Loquat	2.0-2.5	0.12-0.20	1.0-1.8	0.8-1.5	0.18-0.30	—	—	—	—	—
Carambola	1.65-2.6	0.10-0.18	1.2-1.9	1.5-2.0	0.60-1.00	—	—	—	—	—
Mango	1.4-1.7	0.10-0.15	0.9-1.2	1.0-1.8	0.20-0.35	—	5-20	60-120	30-200	20-100
Wax apple	1.26-1.50	0.10-0.12	1.15-1.45	1.60-2.00	0.16-0.20	30-80	—	100-150	70-120	30-50
Custard apple	3.0-4.0(2nd crop) 2.4-3.2(1st crop)	0.18-0.22 0.10-0.14	1.4-2.0 0.5-1.0	0.2-0.7 0.7-1.0	0.34-0.86 0.35-0.55	— —	5-25 —	40-70 —	200-350 —	15-25 —

Source : Chen *et al.*2001, Wang *et al.*2000b.

Table 15.Suggested plant part and age, stage, position or condition to sample for various fruit tree in Taiwan

Fruit tree	plant part and age	stage	position or condition
Citrus	spring cycle leaves 5 to 6 months	during last August to early September	from nonfruit-bearing terminals
Grape (summer fruit)	30-40 days after bud germination	during March to April	from a fruit-bearing twig
(winter fruit)	22-28 days after bud germination	during August to September	
Pear	newly mature leaves	during March to April in plain or during April to May from sloped land	from short fruit-bearing twig
Loquat	mature leaves	during July to September (flower bud initiation stage), and the second is during January to February (middle stage of fruit development)	from fruit-bearing twig
Carambola	mature leaves	June	from nonfruit-bearing twig
Mango	newly mature leaves	during early February to early March	from the middle position of top twig (that has never bloomed and is in pre-flushing condition)
Wax apple	select the second and third newly mature leaves	during August to early September	from a fruit-bearing twig
Custard apple	the forth and fifth leaves	during early to middle December for 1st crop and from May to middle Jan for 2nd crop	from a nonfruit-bearing twig

Source : Chen *et al.* 2001,Wang *et al.*2000b.

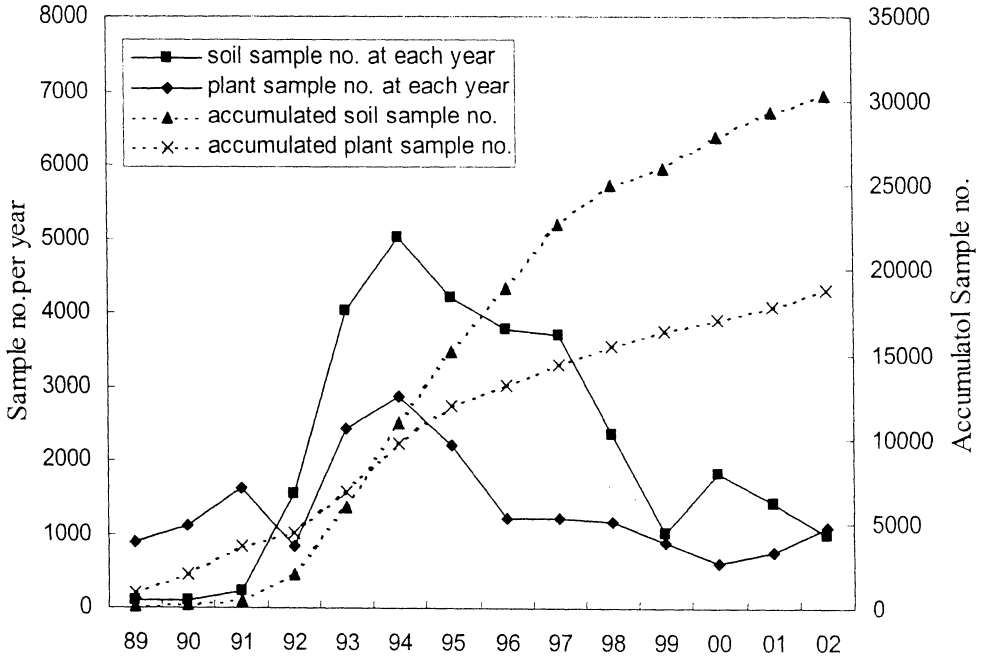

Fig.5. Annual and accumulated soil and plant sample number during 1989 to 2002